Effect of Flexural and Shear Reinforcement on the Punching Behavior of Reinforced Concrete Flat slabs

By

Amr Bakr Ismail

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
Structural Engineering

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Title of Thesis:

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Key Words:

Punching, flat slabs, flexural reinforcement, shear reinforcement, crack pattern.

Summary:

In this research, seven samples were tested in the laboratory, representing a half- scaled model . The samples were a flat slabs with dimensions of 1050 x 1050 mm and a thickness of 100 mm. They were loaded with a square column 150 x 150 mm. Some variables were considered, such as distance between stirrups , width of the stirrups , number of branches of the stirrups and number of longitudinal bars at the column-slab connection. The experimental results were compared to those estimated by the Egyptian and international codes . The results showed that the punching strength increased with the increase of flexural reinforcement ratio and increase of stirrups.

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ABSTRACT

Punching is one of the most important phenomena to be considered during the design of reinforced concrete flat slabs. Three main factors affect the punching behavior; namely concrete compressive strength, horizontal flexural reinforcement, and vertical shear reinforcement in the form of stirrups, studs or other forms. This thesis is part of an ongoing research program conducted at the concrete laboratory of the Faulty of Engineering, Cairo University to assess the contribution of horizontal flexural reinforcement and vertical shear reinforcement on the punching behavior of reinforced concrete flat slabs. In the current research, seven half scale specimens are cast and tested. The specimens had dimensions of 1050x1050 mm and a total thickness of 100 mm. All specimens were connected to a square column of dimensions 150x150 mm and supported at the four corners with a span 950 mm. The parameters considered in this research included spacing between vertical stirrups, width of the stirrups, number of stirrups branches and the ratio of the horizontal flexural reinforcement. During testing, ultimate capacity, steel strain, cracking pattern and deformation were recorded. The experimental results were analyzed and compared to values estimated according to the Egyptian and international design codes.

The results of this research revealed the efficiency of flexural and shear reinforcement in resisting punching stresses . The punching strength increased with the increase of area of flexural reinforcement and the increase in number of stirrups in the vicinity of the slab- column connection .

CHAPTER (1): Introduction

1.1 Introduction

Flat slab is commonly used in multi-storey structures , office buildings and parking structures. It is called slab-cloumn structure, which has architectural view and economical use of housing space . Despite the benefits of the flat slab system, one of the major design problems lies in Large bending moments and shear forces at slab-column connections. In addition punching shear failure occurs in a brittle way without warning signs. When punching shear failure occurs column and slab separate from each other which can lead to collapse the structure. In order to avoide the faiure of slab-column connections around the column einforcement profiles are provided such as bent bars, transverse hidden beams with stirrups, fibers, HSC and steel I-beams. These precautions improve the punching shear capacity and hence the strength of slabs.

Punching failure is a brittle failure caused by shear diagonal cracks developed through the full slab thickness forming a frustum pyramid in rectangular columns and a trenched cone in circular ones. Punching is a common failure that can be seen in reinforced concrete flat slabs as well as other structural elements such as foundations. Many factors affect the punching capacity of slabs such as concrete strength, column to slab aspect ratio, flexural reinforcement, shear reinforcement and boundary conditions. Design codes deal with the punching failure problem in different ways. For example, the current Egyptian Code of practice E.C.P. (203-2007) [1] highly underestimates the punching capacity by neglecting the contribution of the vertical and horizontal reinforcement in calculations. While, the American code (ACI318-14) [2] neglects the effect of the horizontal reinforcement and the European code Euro-Code 2 [3] considers both of them. In addition, the location of the critical section of punching varies among the design codes from half to double the effective slab depth measured from the column face.

Several analytical models were proposed over the past decade to simulate the punching behavior of concrete slabs. The first of these was the Kinnunen and Nylander model [4] who neglected the contribution of reinforcement to the punching capacity of concrete. Similar models were introduced. In addition there are other models such as the plasticity approach, shear friction model, truss model and yield line model. Such models give an indication of the complexity of the punching problem in concrete slabs.

Increasing the punching capacity of RC slabs can be done using different methods such as drop panels, shear reinforcement in the form of studs or stirrups and bent up bars. Strengthening of existing slabs in punching can be performed using advanced composite materials such as carbon fiber reinforced polymers (CFRP), and glass fiber reinforced polymer (GFRP). Ebead tested slab column connections strengthened with CFRP strips and GFRP laminates. Based on the test results, he concluded that the use of CFRP strips and GFRP laminates with the suggested dimensions were sufficient to achieve positive results for the flexural strengthened specimens. In addition, flexural strengthened specimens using CFRP strips showed an average gain in load capacity of 40 % over that of the un-strengthened specimens. Moreover, flexural strengthened specimens using GFRP laminates showed an average increase in load carrying capacity of 31 % compared to that of un-strengthened specimens.

Megally conducted a series of tests on slab column connections subjected to concentric and earthquake loads. He concluded that providing a slab column connection with drop panel increased the strength to the target value without significant improvement in ductility and energy absorption capacity. Megaily and Ghali [5,6] conducted a series of reversed cyclic tests of edge slab column connections reinforced with stud shear reinforcement. The test variables were the provision of stud shear reinforcement, the spacing between shear studs, and the value of shearing force transferred between the column and the slab. They concluded that, without shear reinforcement, slab column connections subjected to earthquakes may fail in a brittle punching shear mode at relatively low drift ratios. In addition, provision of shear studs significantly enhances the ductility and maximum inter-story drift ratios that the connections can undergo without punching failure.

Brooms proposed a combination of bent bars and stirrups to be installed in the column vicinity in order to eliminate the brittle punching shear failure of slab column connections. In his research, the tested specimens were provided with bent bars as hangers into the column in combination with stirrup cages from welded wire fabric over a fairly large area around the column. This concept turned out to be very effective in creating an extremely ductile structural system.

Out of the above mentioned strengthening systems, using flexural reinforcement in addition to stirrups proves to be the most practical method to be applied to enhance the punching behavior. This system is applied throughout the research program presented in this thesis There are many parameters affect punching shear strength like reinforcement ratio, the compressive strength, size and geometry of column ,type of reinforcement and the effective depth of the slab. Figure (1.1) shows an example to floor failure due to punching, while figures (1.2) and (1.3) illustrate the concept of the punching failure. The increase in reinforcement ratio while keeping increases the punching shear strength and prevents development of the tensile cracks due to bending which leads to a good transfer of loads in slab-column connection.

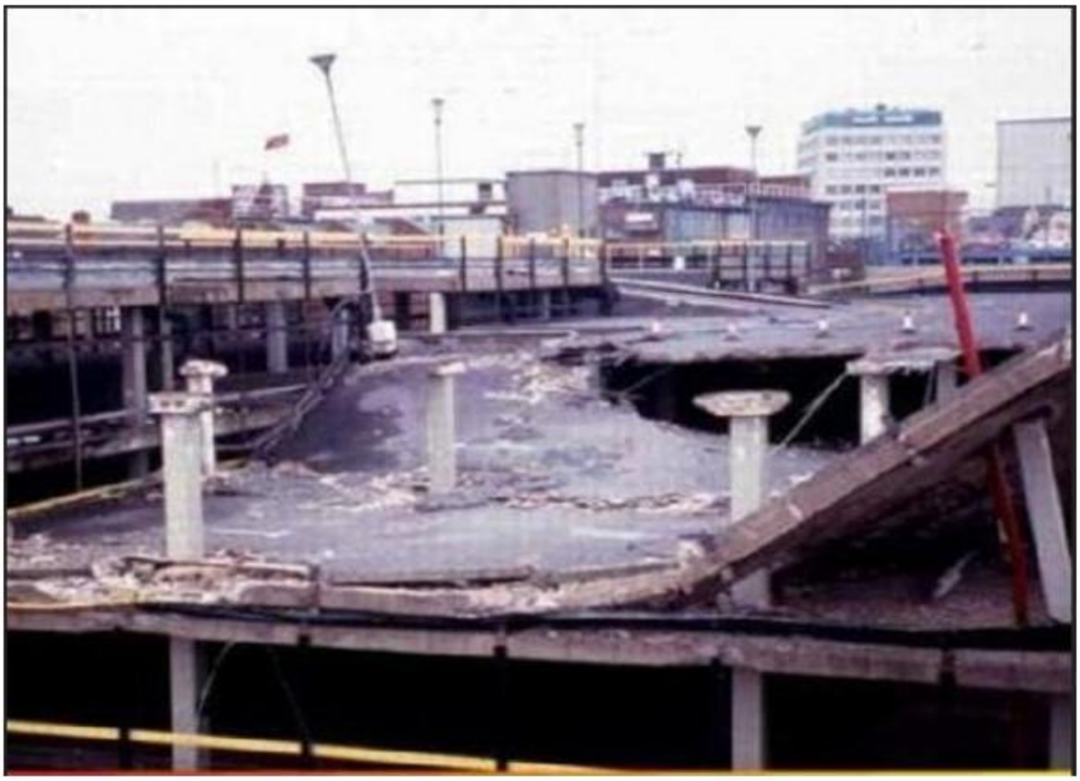

Figure (1.1): Building Collapsed due to punching failure

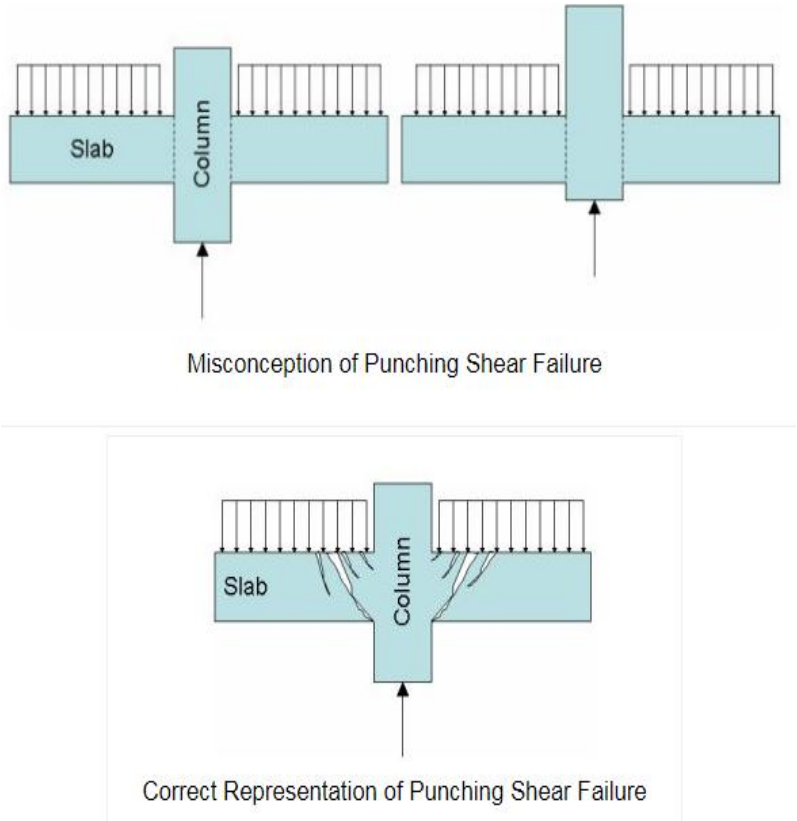

Figure (1.2): The main concept of the punching failure

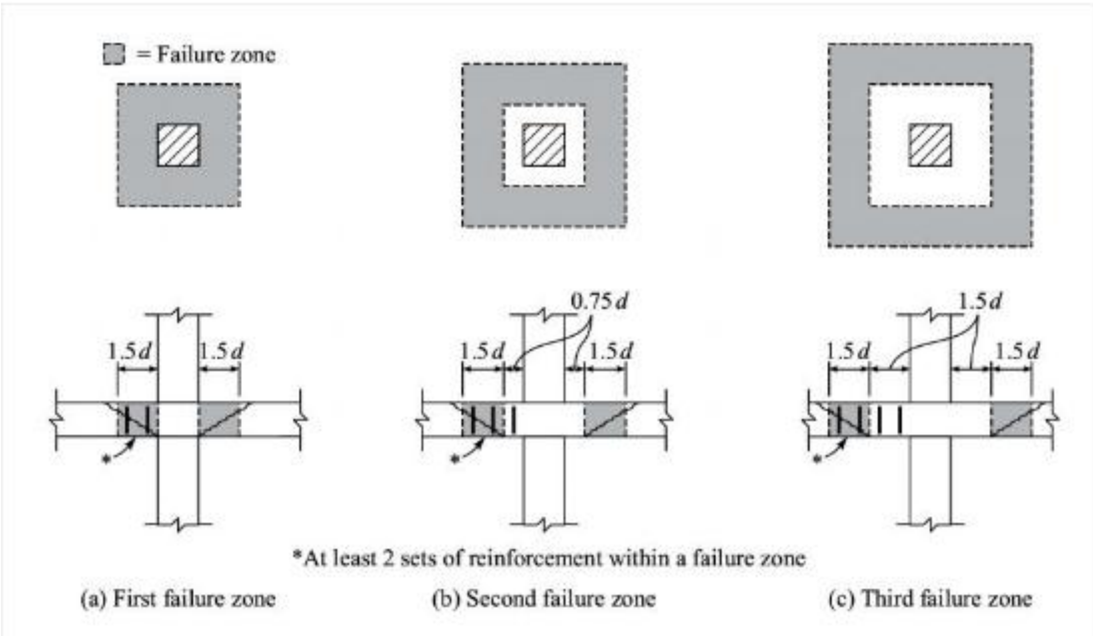

Figure (1.3): Various punching failure zones

1.2 Objectives

In this thesis at first , it is released a comparison between different codes like Egyptian code, ACI American code, euro code due to calculate punching shear loads failure. second , Another comparison between theoretical and experimental results. It is contained three variables in 7 samples